Jet Propulsion Laboratory
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Future Plans for NASA's Deep Space Network

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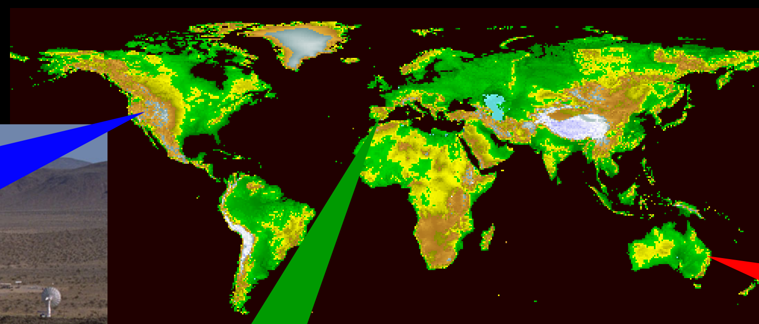
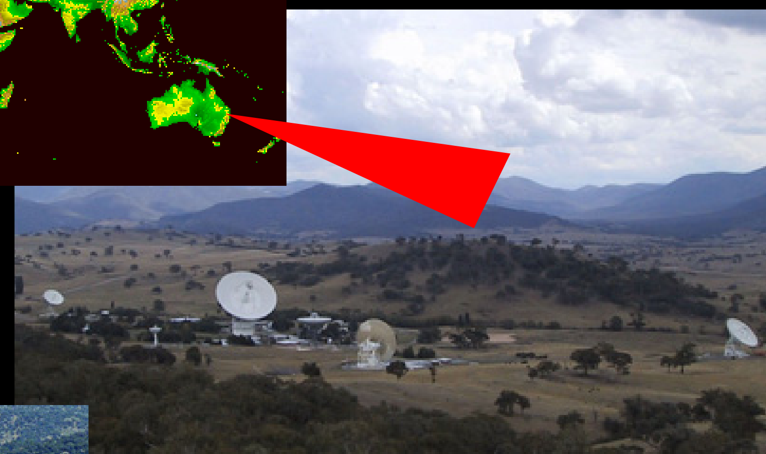
The Deep Space Network

The NASA Deep Space Network (DSN) is an international network of antennas that supports interplanetary spacecraft missions and radio and radar astronomy observations for the exploration of the solar system and the universe





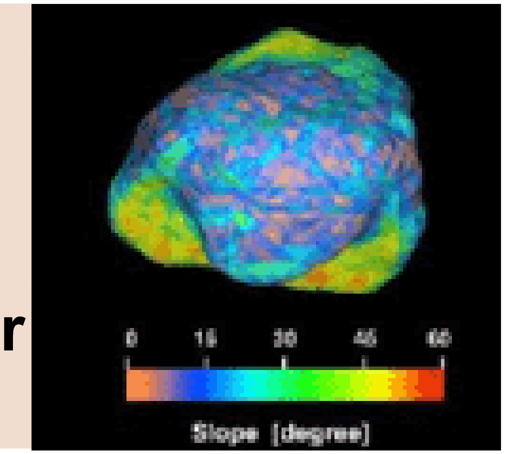
Goldstone
Operated by ITT for NASA/JPL

Canberra
Operated by Raytheon for CSIRO

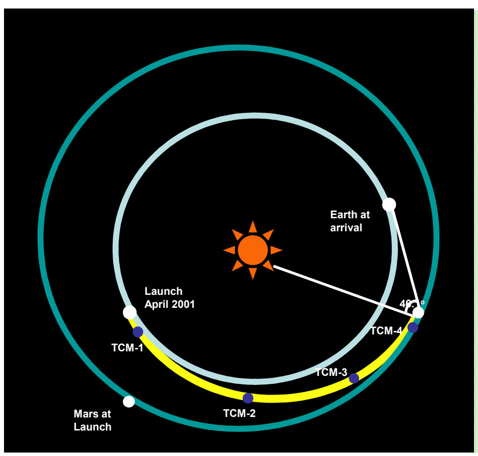
Madrid
Operated by INSA for INTA

DSN Enablers for Primitive Body Exploration

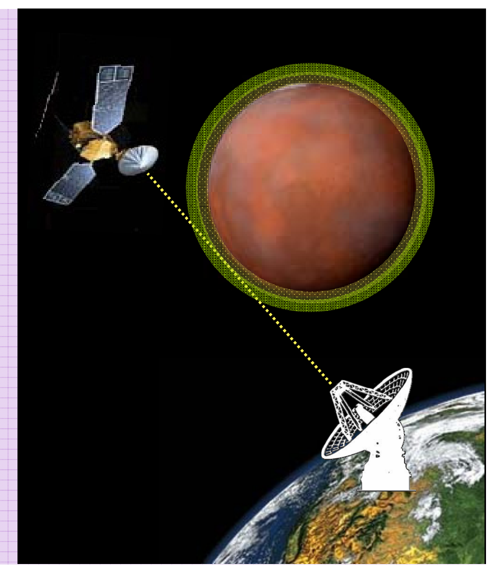
Communication



Goldstone Radar



Navigation



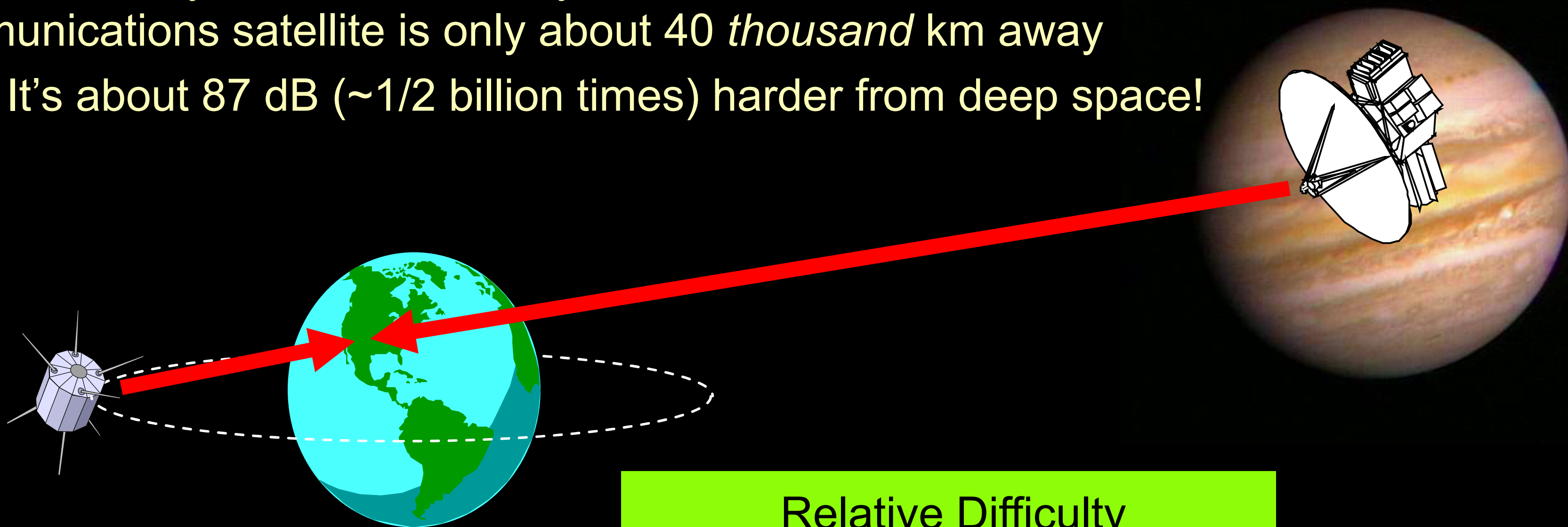
Radio science

Why is Deep Space Comm Difficult?

Communications performance decreases as the square of the distance.

Jupiter is nearly 1 *billion* km away, while a GEO Earth communications satellite is only about 40 *thousand* km away

– It's about 87 dB (~1/2 billion times) harder from deep space!



Relative Difficulty

Place	Distance	Difficulty
Geo	4x10^4 km	Baseline
Moon	4x10^5 km	100
Mars	3x10^8 km	5.6x10^7
Jupiter	8x10^8 km	4.0x10^8
Pluto	5x10^9 km	1.6x10^{10}

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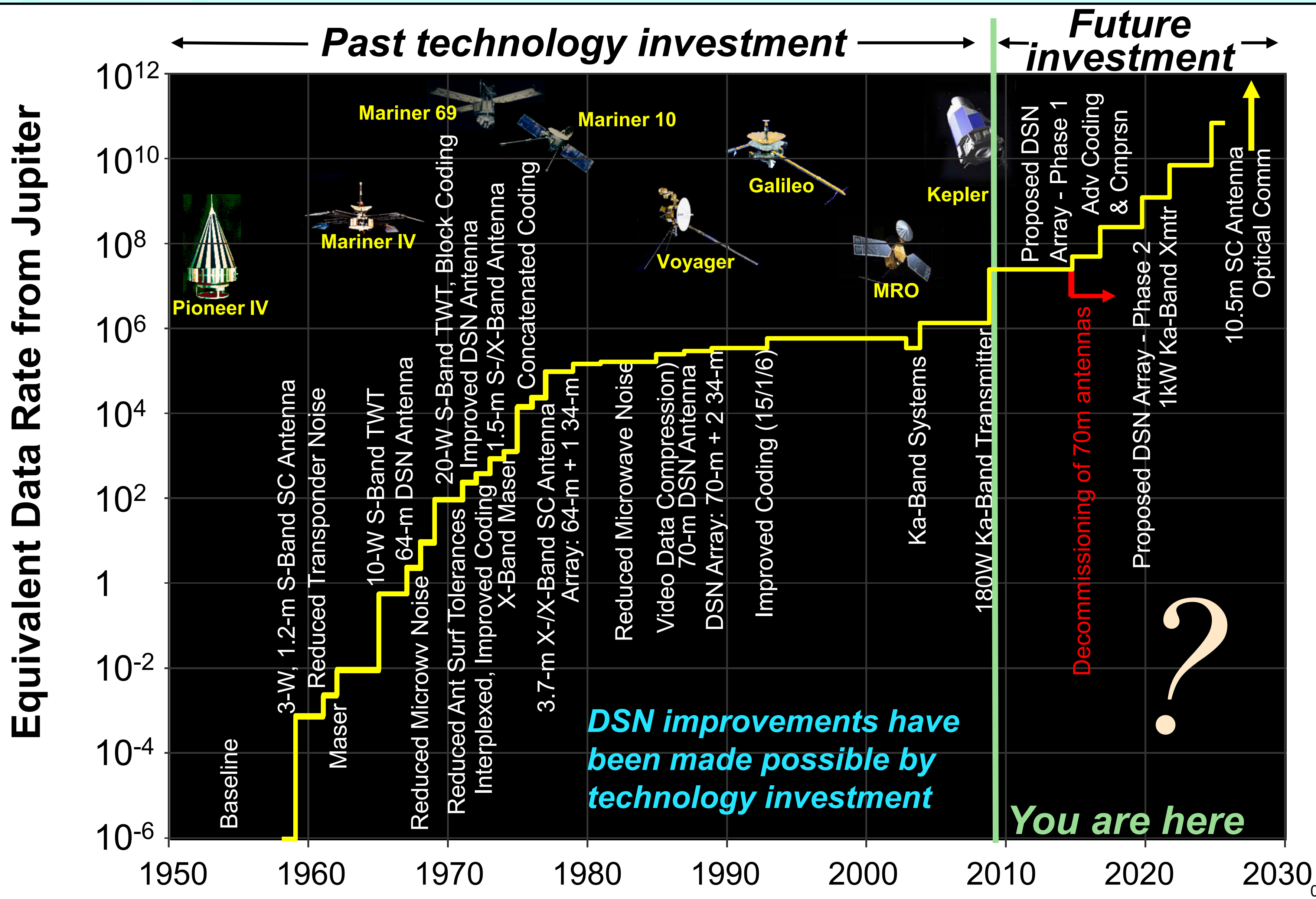
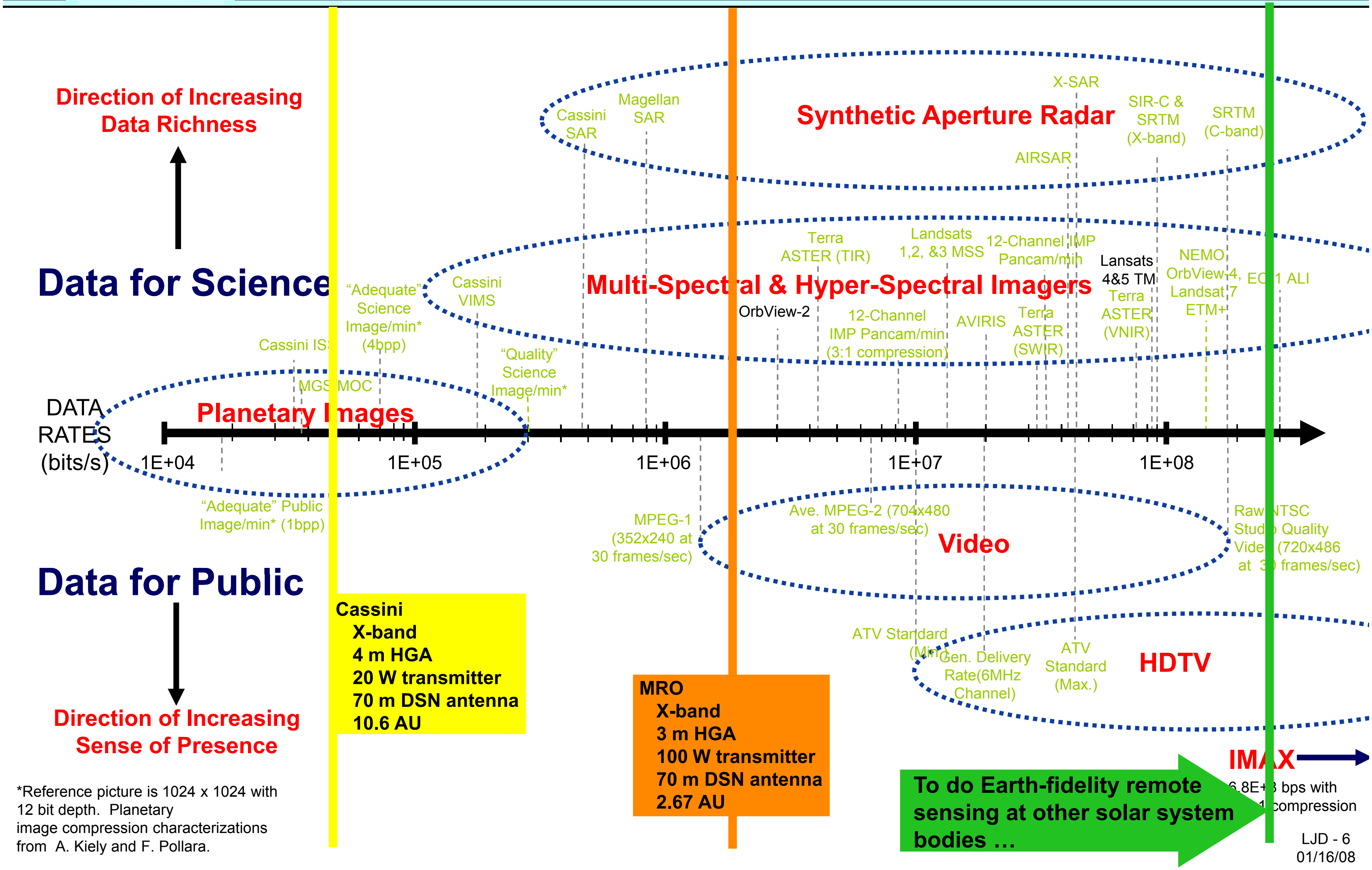
International Primitive Body Exploration Working Group

Future Plans for NASA's Deep Space Network

History of Deep Space Telemetry

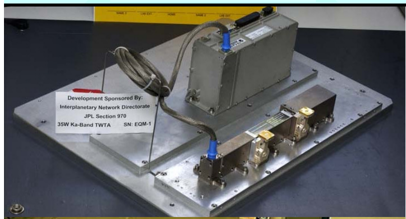


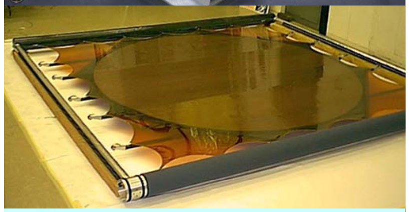
Analogy: Planetary Remote Sensing Today

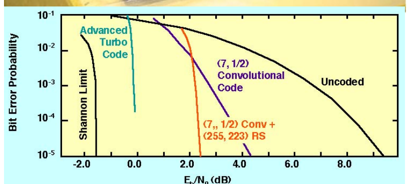


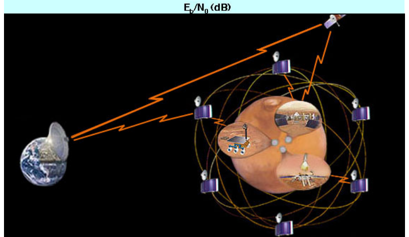
*Reference picture is 1024 x 1024 with 12 bit depth. Planetary image compression characterizations from A. Kiely and F. Pollara.

Possibilities for Improving Comm





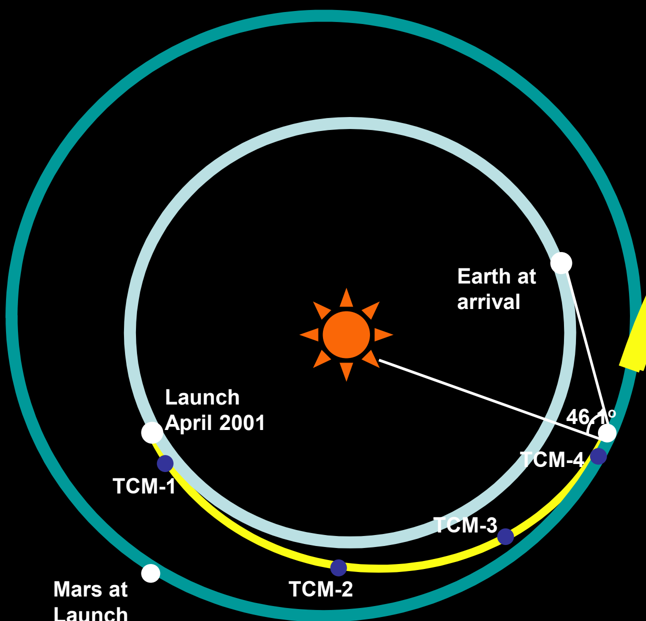


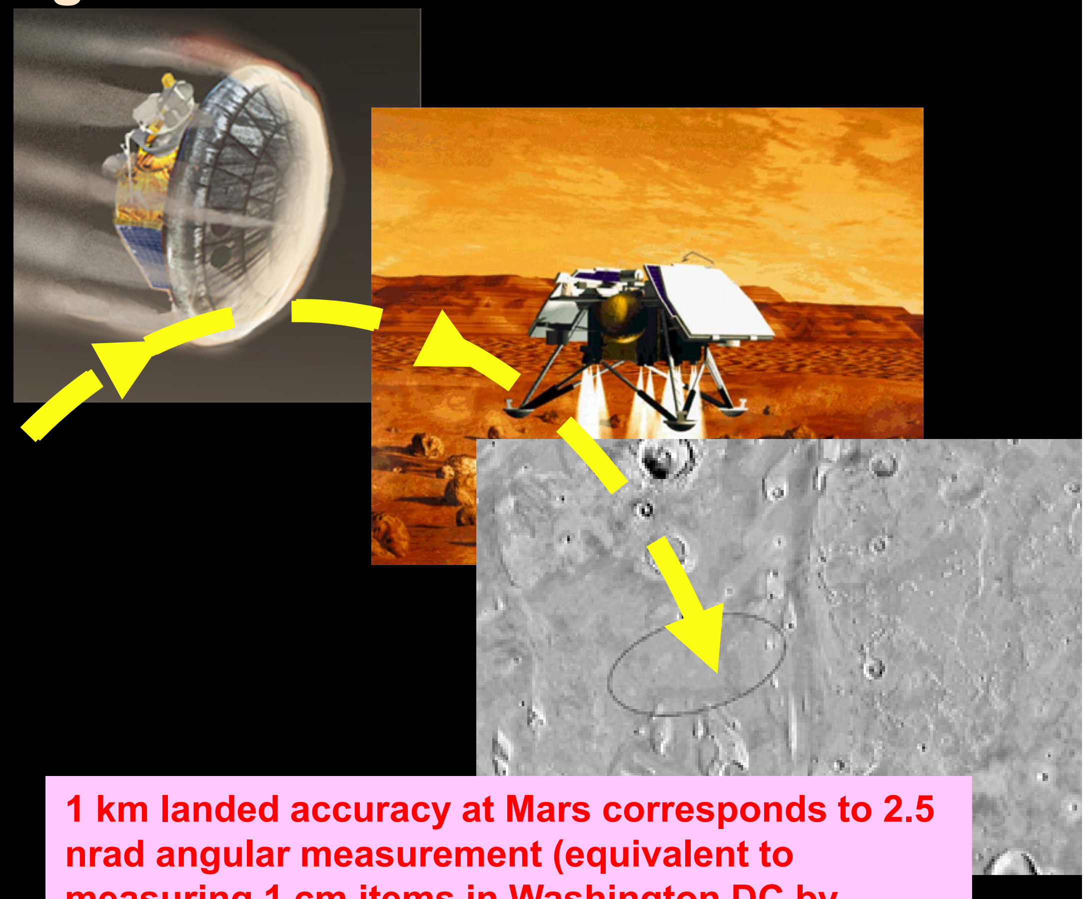


- **Ka-band provides a factor of four gain**
- **High-power spacecraft transmitters**
  - **200 W demonstrated at Ka-band, 1 KW is possible**
- **Large, deployable spacecraft antennas**
  - **5m is feasible today at Ka-band, 10m in the future**
- **Advanced coding and compression**
- **Increased use of relays (space networking)**
- **Arraying of DSN antennas**
  - **In practice today, allows growth with increasing needs**
- **Optical comm: even more for certain missions**
- **Bottom line: 1,000x increase for most deep space missions is possible over 25 years**
  - **Factor of 1,000,000 for some mission types is possible**
- ***If gain is not need, can take reduction in mass and power instead!***

Why is Deep Space Navigation Difficult?

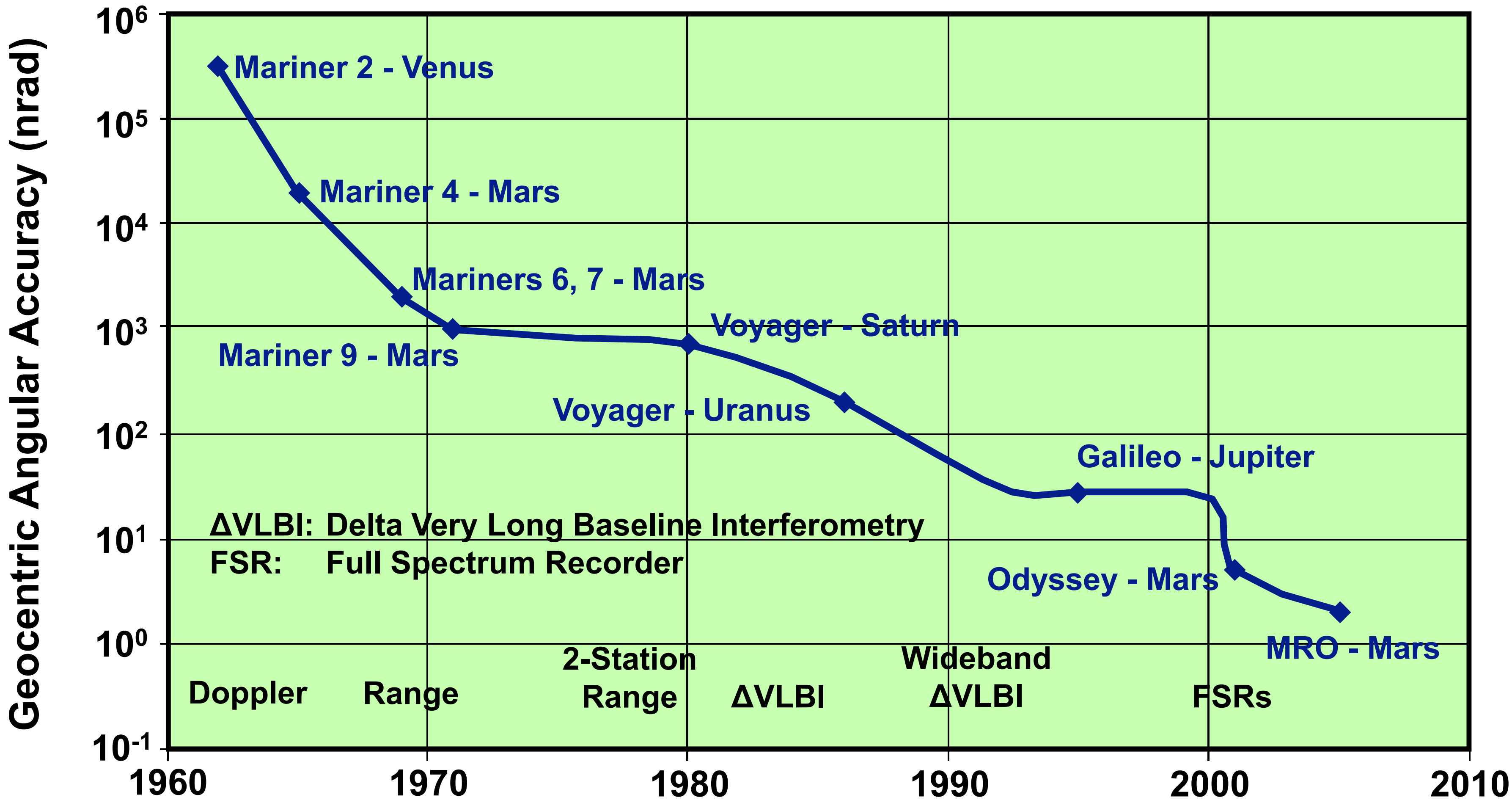
- Deep space missions use comm links to help with nav
- Very accurate positions needed over very large distances
- Also must "navigate" the target bodies!
- For small bodies
  - Very limited before-launch understanding of the target
  - Must adapt in near real-time





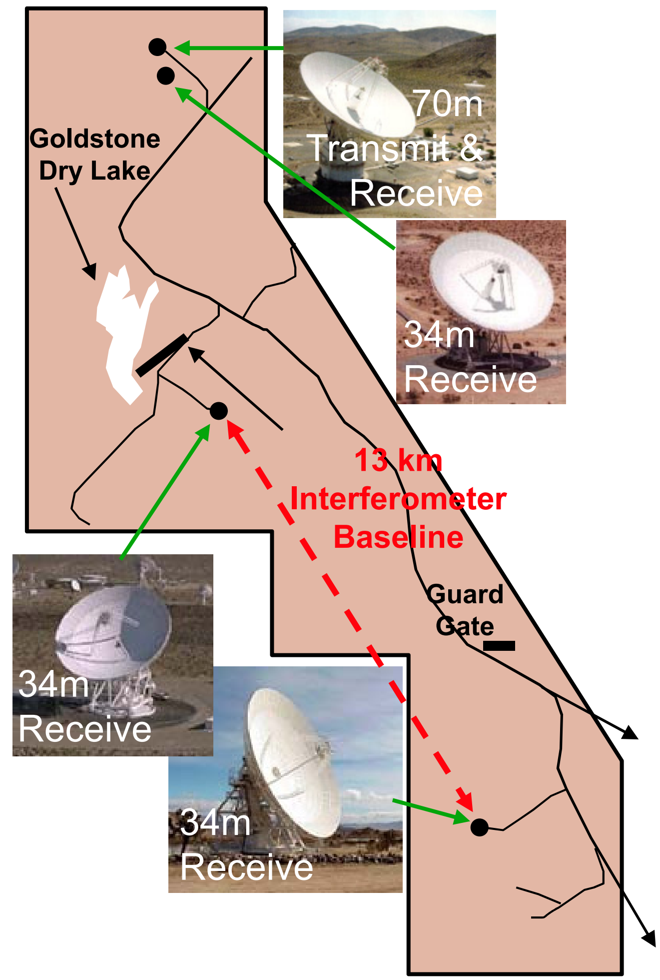
1 km landed accuracy at Mars corresponds to 2.5 nrad angular measurement (equivalent to measuring 1 cm items in Washington DC by observing from L.A.)

History of Deep Space Angular Tracking



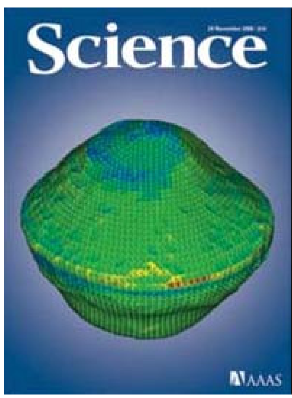
The Goldstone Radar Facility

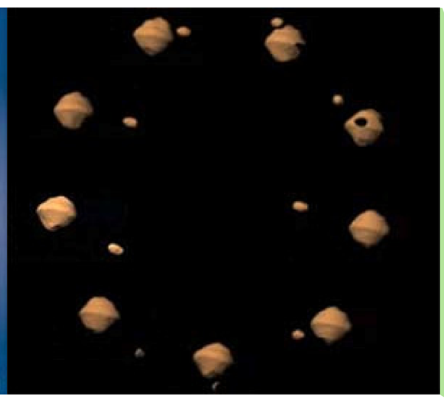
- **Unique facility for high-res ranging and imaging of planetary and small-body targets**
  - **500 kW X-band transmitter**
  - **Ultra-sensitive DSN receivers**
  - **Can be used in conjunction with Arecibo**
- **Provides wide variety of information**
  - **Surfaces: images, topography, ice distribution, physical characteristics, chemical composition**
  - **Dynamics: Orbits, rotations, spin axes**
- **Users**
  - **Most planetary missions**
    - **Landing site evaluation, emergency support, …**
    - **Mission science support**
  - **NASA approved science investigators**
  - **NASA Near Earth Asteroid Program**
  - **Lunar Exploration Program**
  - **Orbital debris observations**



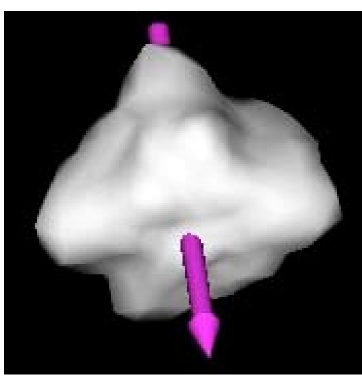
Goldstone Radar: Recent Highlights

- **Discovery of Mercury liquid core**
  - Supports Messenger mission





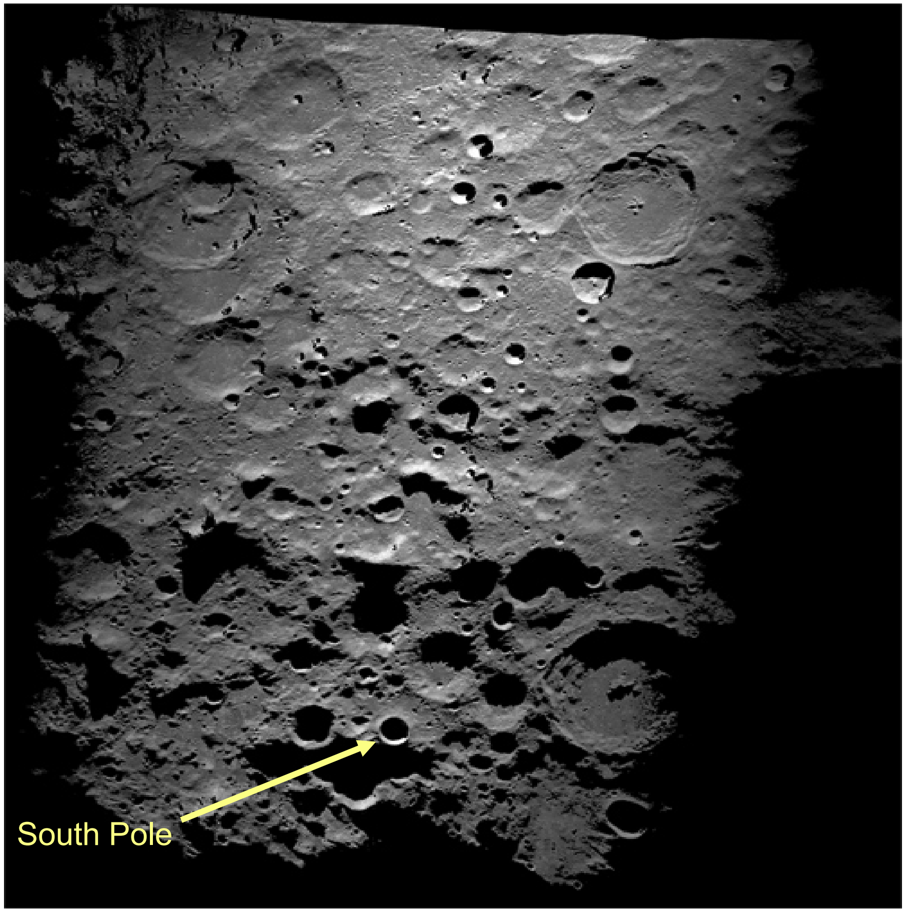
- **Radar Imaging and Topography of Unusual Asteroids**
  - Support NEO Program
  - Asteroid 1999 KW4 – A binary pair of asteroids, with the larger object being extremely oblate because it is close to it's breakup rotation rate



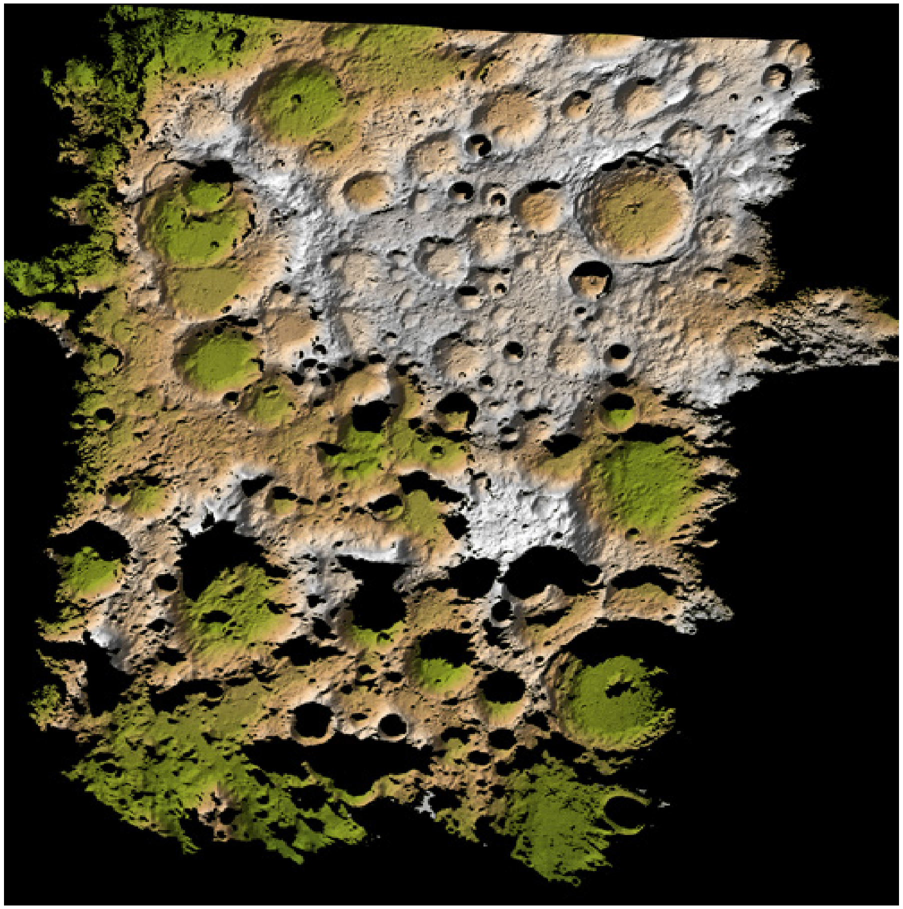
  - Asteroid 2000 PH5 – Asteroid found to increase spin rate due to sunlight torque (Science, 13 April 2007)

Goldstone Radar: Lunar Science

- **Observations with unprecedented imaging (20m resolution) and topography resolution of Lunar South Pole**



Radar Image



Digital Elevation Map

Future Plans: Goldstone Radar

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Increased Radar Resolution

- **Improving imaging/topography resolution of Goldstone Radar from 20 m to 1 m for Near-Earth-Objects and Moon**
- **Have achieved 4-m resolution on NEOs; working on 4-m resolution for Moon**
- **Broader band transmitter could be used to achieve 1-m resolution**
  - **Assuming target is close enough to Earth, of course**
- **Considering developing a southern hemisphere radar capability in Australia**

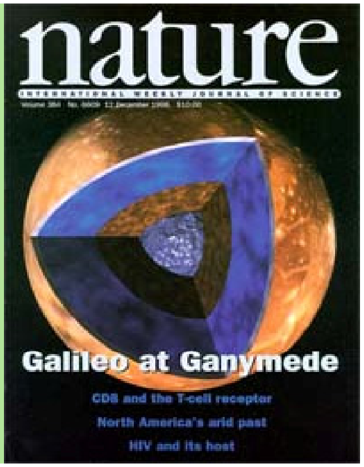
Radio Science

- **Scientists use comm links between spacecraft and Earth to monitor phase, frequency, amplitude, and polarization of radio signals**
  - **Radio Science instruments fly on almost all planetary missions**
  - **Opportunities to propose radio science investigations are in mission AOs**
- **The links are used for wide variety of scientific investigations**
  - **Solar System: atmospheres, ionospheres , interiors, masses,**

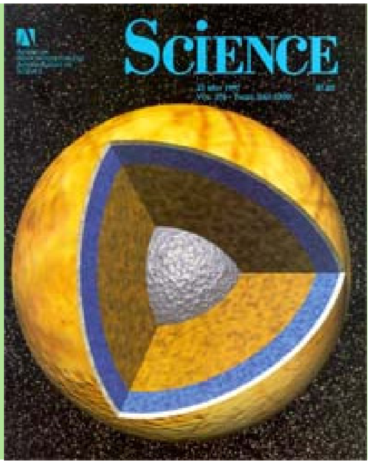
    rings, surfaces, orbits, magnetic fields, particle size distribution
  - **Sun: solar wind and corona**
  - **Fundamental physics: Gravitational waves and redshift, general relativity**

Radio Science: Recent Examples

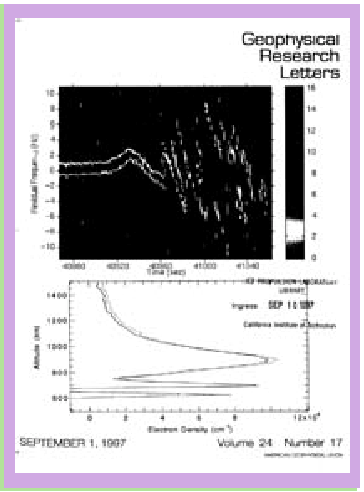
Centrally condensed interior of Ganymede (Galileo)



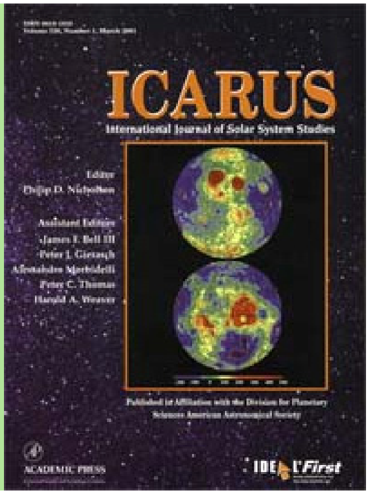
Oceans on Europa? (Galileo)



Electron density profile of Mars ionosphere (MGS)

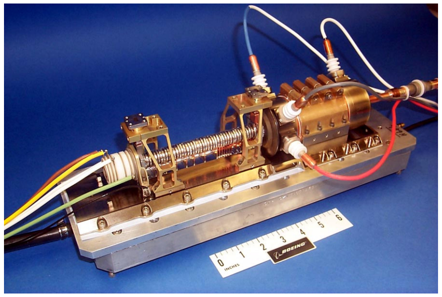


Gravity field of Moon (Lunar Prospector)



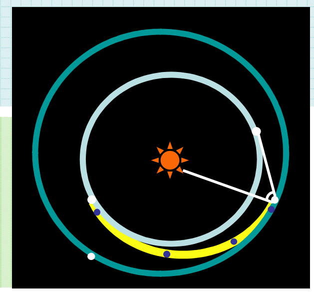
Future Plans: Radio Science

- **Increased use of Ka-Band (32 GHz) can enable new science observation**
- **New spacecraft radio instruments would have dramatically improved accuracy or capabilities**
  - **New transponder with up to 10X improvement in Doppler/range accuracy (DSN and space components)**
    - **Studies of interior structure (e.g., oceans)**
  - **Modifications to NASA's Mars in-situ radio would enable uplink and crosslink science observations – and can be used at other bodies**
    - **Studies of atmospheres and near-surface properties**
- **All these new capabilities can also improve navigation**

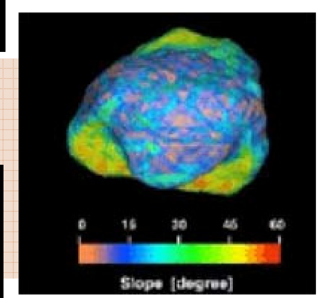


Summary

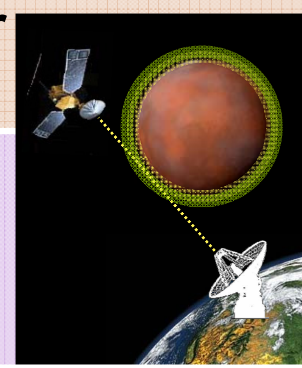
- **The DSN stands ready to enable future primitive body exploration**
- **Communication**
  – **Would grow capability with mission needs: 1,000x or more improvement**
  – **Improvement can be taken in reduced mass and power for small spacecraft**



- **Radio Navigation**
  – **Precision could increase by up to 10x**
- **Goldstone Radar**
  – **Would continue to improve resolution for primitive body observations (esp NEOs)**



- **Radio science**
  – **Would work in concert with flight-side developments to push the envelope**



Backup

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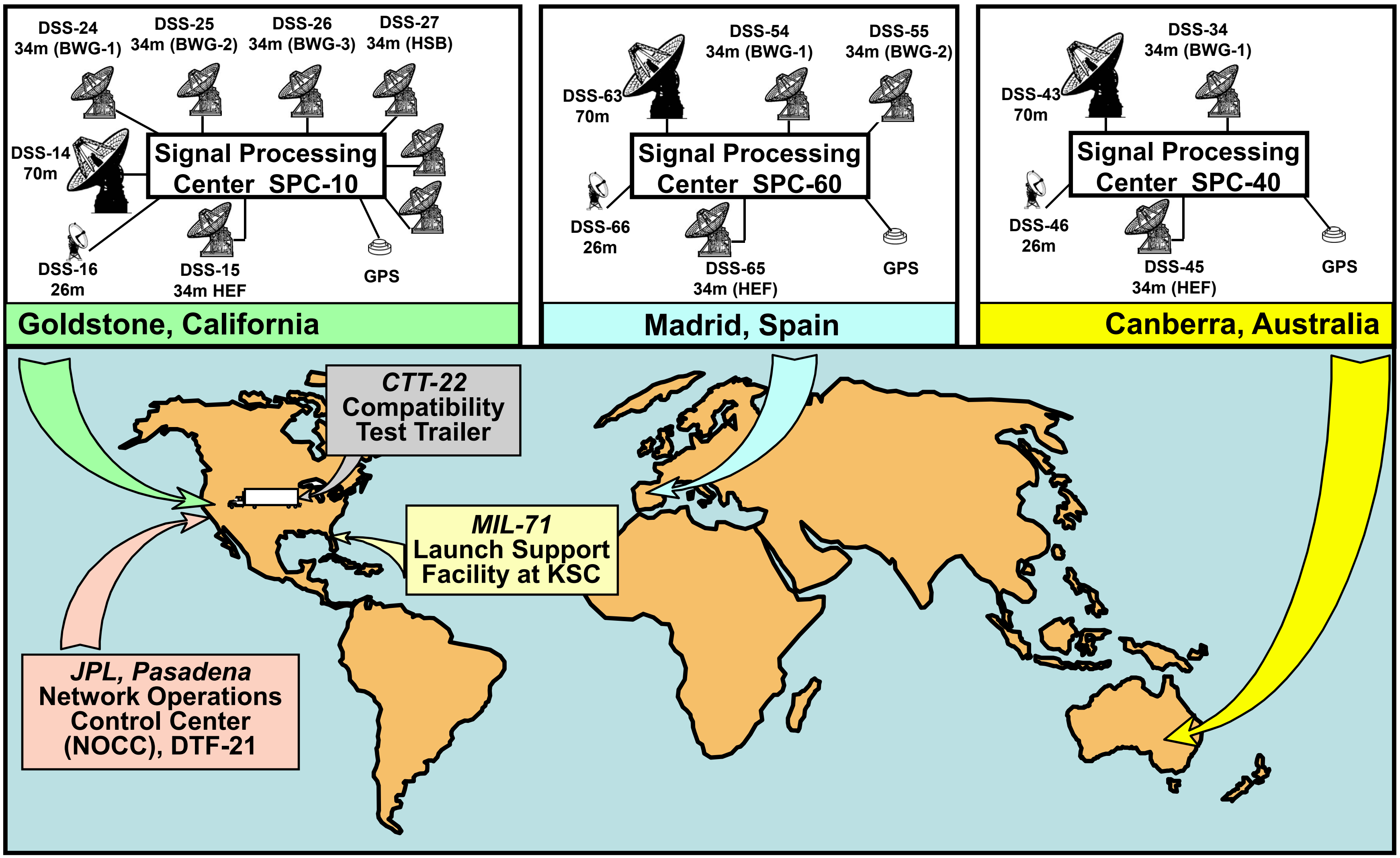
DSN Facilities



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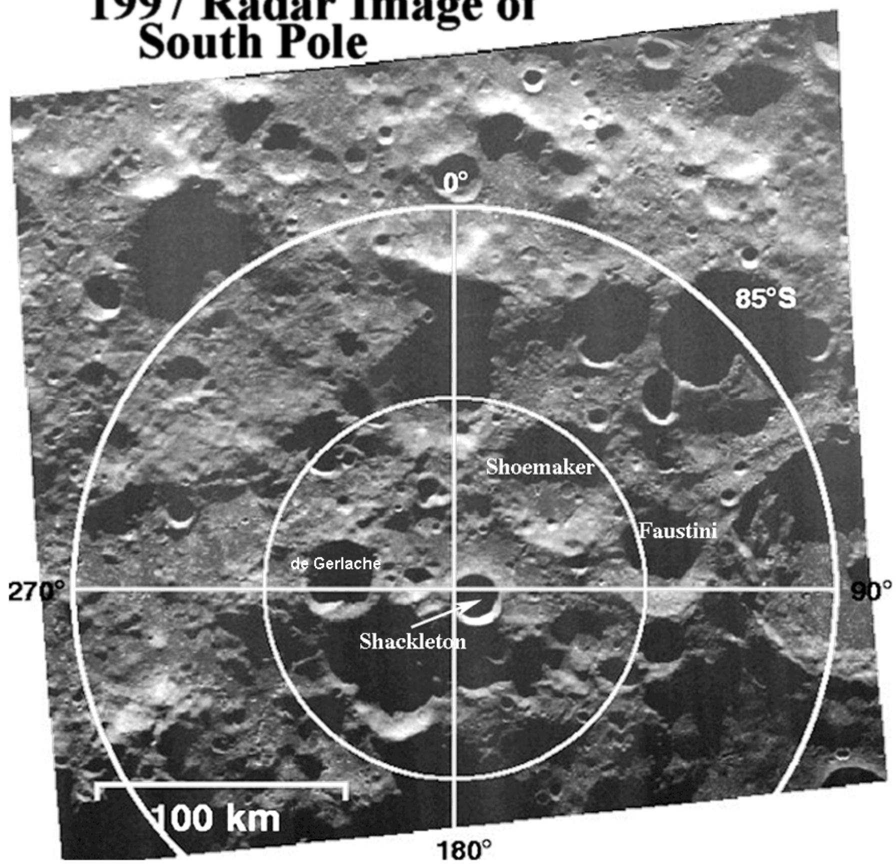
Radar vs Optical Imaging of Moon

- **Radar observations provide image details in areas without solar illumination and yield co-registered topography**

1997 Radar Image of South Pole



Clementine Optical Mosaic of South Pole